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RESEARCH DEPARTMENT

REPORT ON THE INTERNATIONAL CONGRESS ON ACOUSTICS
COPENHAGEN 1962

Report No. A-075

(1962/51)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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1. INTRODUCTION

The International Congress on Acoustics held in Copenhagen from 21st to 28th August 1962 was the fourth of a series held at three-yearly intervals. The previous Congress, held at Stuttgart in 1959, was described in Research Report A-057; it is proposed that the next should be held in Liège in 1965. This year the B.B.C. was represented by Messrs. H.D. Harwood and F.L. Ward of the Research Department and Mr. A. Brown of Building Department.

2. INTERNATIONAL CONGRESS ON ACOUSTICS

2.1. General

The opening session took place in the Concert Hall of the Tivoli and the remainder in the various lecture theatres of the Royal Technical University. The conference was extremely well organised and one improvement over the arrangements for previous years was that it was possible, with some effort, to reach any of the lecture theatres in the five minutes allowed between contributed papers. To make this possible loud signals were radiated from loudspeakers one minute before the end and at the end of each lecture period, and the timing rigorously enforced. The rooms generally were well designed, and in a number the radio microphone which was always provided for the author was not needed.

The opening session consisted, apart from the speeches, of orchestral items specifically intended to show the acoustic properties of the hall. There was also a general paper by the Nobel prizewinner, Dr. G. Von Békésey, on "The Artistic Approach and the Scientific Approach - Some Personal Experiences Illustrated by Art Objects"; in this paper the author skilfully discriminated between the factors of lasting and those of lesser value in each subject.

The remainder of the conference proceeded, as on previous occasions, with invited papers lasting an hour each in the morning and an afternoon session consisting of contributed papers, for each of which twenty minutes was allowed. This year the contributed papers were distributed at the beginning of the conference and it was possible to examine some before they were read. It would have been even better if the papers had been received in time for them to be studied properly and then the twenty-minute period at the conference restricted to additional information given by the author (the papers are restricted to the space occupied by about 2000 words) and discussion.

There were 14 invited and approximately 310 contributed papers divided somewhat arbitrarily into the following sections:

Section	
G	35 Papers on Speech Analysis and Synthesis
H	47 Papers on Physiological and Psychological Acoustics (apart from Speech Analysis and Synthesis)
J	27 Papers on Molecular Acoustics: Investigations of molecular properties by acoustic means
K	29 Papers on Ultrasonics and Underwater Sound: Ultrasonic Techniques in General
L	42 Papers on Noise Control: Noise problems in general, insulation in connection with specific noise and vibration problems
M	38 Papers on Room Acoustics: Sound absorption and insulation in general - Acoustic properties of rooms
N	40 Papers on Electroacoustics: Transducers, measuring methods in general
O	39 Papers on Physical Acoustics: General theoretical acoustics, radiation problems, non-linear acoustics, etc.
P	22 Papers on Mechanical Vibrations
P5	6 Papers on Musical Acoustics

There were the usual social occasions and on the afternoon of 23rd August, visits were made to various places of technical interest.

The most outstanding feature of the conference was the use made of computers, not so much for calculations, as for processing a signal, e.g., speech or noise, to imitate the effect of introducing some piece of apparatus into the circuit. The signal is applied to an analogue-to-digital converter and fed into the computer. This is programmed to operate on the signal, modulators, filters and time delays being simulated, and then a digital-to-analogue converter reconstitutes the processed signal. The circuit elements mentioned were simulated in numbers which would require several man-years of work and to an accuracy which is probably impossible to achieve in any other way. In one experiment concerned with bandwidth compression, the computer was programmed to provide the equivalent of 200 bandpass filters 60 c/s wide, 50 dividers and 50 multipliers. The time taken for one experiment on this system was one day; for example, the bandwidth of all the filters could be changed in a few hours. In other cases computer-type circuits were specially constructed, particularly for speech synthesis and analysis which was the subject of a large number of papers, the economic driving force being bandwidth compression.

An outline follows of some of the papers bearing closely on the work of the Corporation; for convenience the contributed papers are grouped in the categories given above.

2.2. Invited Papers

Recent Advances in the Subjective Measurement of Noise - D.W. Robinson

The lecturer reviewed the work of his own and other laboratories in the field. He expressed a warning about other people reading more into his results than he himself claims.

The advantages and difficulties of subjective "measurements" were discussed together with their relations to laboratory measurements which could be conceived to be made under perfect conditions for measurement. In this type of investigation a balance had to be struck between precision on the one hand, and obtaining the correct environment for the listener on the other. It was the usual rule that the more realistic the environment the more vague the answers which could be obtained from experiments. He briefly described measurements on car noise carried out using listener panels sitting on the side of the road, as an example of a subjective study.

Another type of subjective measurement had to do with the determination of equal-loudness contours and he showed a comparison between the equal-loudness contours determined for different angles of approach to the head and those calculated from direct ear measurements.

In dealing with noise, other quantities than simple sound loudness levels might be taken into account, for example, the perceived noise level, which refers to sounds which are equally disturbing. However, a number of variations in listening conditions can produce appreciably different answers. Housewives on their own doorsteps gave very different answers to the same questions asked of a specially convened panel sitting at the side of a road. And if questions are asked about a noise occurring outside a building (for example aircraft noise) of people both inside and outside the building, the answers indicate that a lower level is tolerated indoors than outside.

Criteria for the Design of Concert Halls and Opera Houses - L.L. Beranek; Bolt, Beranek, and Newman Inc., U.S.A.

In this important paper Beranek surveyed the result of a study of the acoustics of concert halls covering a period of seven years. Twenty-two well-known conductors and twenty-three professional music critics have been questioned in great detail regarding the acoustics of fifty-four concert halls throughout the world. As a result of their comments it has been possible to divide these halls, all of which have proved themselves to be acoustically satisfactory for music, into five groups - excellent, very good, good to very good, good, and fair. Further, the acoustical factors contributing to the assessment of each hall in this way have been determined. The assessment of the relative importance of these attributes provides criteria for the design of concert halls and the author used the Philharmonic Hall in New York as an example of a hall designed with the aid of these criteria.

The author's researches had shown that the most important factor relating to the excellence of concert halls is the "initial time delay gap" which refers to the difference in time between the direct sound of the orchestra and the first major reflection. He showed a diagram of results where the value assessed for each of the halls studied was plotted against this quantity. He declined to identify the halls in general, the exception being the Royal Albert Hall, which had a unique position at one point of the graph, and whose reputation is presumably too well-known to be harmed by any of his comments.

The value of the average reverberation time was also very important and he indicated reverberation times which seemed appropriate for romantic, classical, and baroque type music. A suitable average value for all types of music would be 1·8 to 2·0 sec. These figures, which assume a full hall, are largely independent of the volume of the hall. The loudness of the received sound was also important and so was diffusion. However, the latter was not as important as other factors; it was sufficient to divide halls into those having negligible diffusion, some diffusion, and adequate diffusion.

There were negative qualities to be subtracted from the rating value of the hall, including the presence of selective absorption, flutter echoes, focussing effects and the like.

He referred to the calculation of the value of the rating for the halls studied. For this purpose two positions in each hall had been taken, and the value averaged. The Vienna State Opera House had the highest value with 96 points on the 100 point scale, while the Royal Albert Hall with 55 points was the worst. The scale was set so that 50 points was the border line between halls suitable and unsuitable for music. The author did not consider that his was by any means the last word in methods for rating halls, but thought that it would act as a guide for future work.

The last section of the paper dealt with the new Philharmonic Hall in New York. Although the hall will not be open until September, a "tuning week" had been set aside during May; during this week nine special concerts were held for the benefit of a judging panel of fifteen musicians and critics. As a result of their comments a number of adjustments had been made. The concert programme had included a specially commissioned work called "Catacoustical Measure", intended for acoustical analysis, although it was stated that the music had some value in itself. Each individual wrote his comments on cards independently of the others; even so the degree of unanimity in their comments about the results of changes in the hall was surprisingly high for this type of subjective experiment.

The author described the hall as basically rectangular in plan, although it had a moderately widening section towards the rear. Arrangements had been made to hang a series of panels to act as reflectors or diffusers over the stage and over the auditorium, and as a result of the tuning tests an additional series of these was also fitted. A screen on the stage, nominally acoustically transparent, was arranged so that it was possible to change the acoustical treatment to some extent if it was considered necessary at any time. An organ was to be installed.

The average reverberation time for the full hall, measured with suitable absorbers placed in the seats as a dummy audience, was of the order of 2·5 sec between 250 c/s and 1 kc/s.

Sound Insulation Requirements between Dwellings - Ove Brandt

Professor Brandt started by tracing the history of European specifications for sound insulation between dwellings. The need for standards had arisen with the use of lighter building materials than those traditionally used. As the brick wall had been found to be satisfactory in general it was the natural starting point for a standard, and the first standards were basically a statement of the average sound insulation of a 2 × 4½ in brick wall. Different countries had produced somewhat different standards and the lecturer showed a diagram where all the common standards were reproduced in the form of curves of acceptable sound insulation against frequency. For the purposes of illustration of his lecture he used the British standard.

Although this first approach was satisfactory as a starting point, most countries had undertaken laboratory experiments and surveys in buildings to assess requirements. The results obtained in the surveys depended very much on the way in which they were carried out and on the sort of questions which were asked. One of the particular difficulties in designing specifications is to determine the shape of the curve of sound insulation against frequencies required; differently shaped curves can describe similar subjective effects and it is partly for this reason that different curves have been produced by the various authorities. The result, however, is that standards for sound insulation in buildings tend to vary from country to country and some countries' standards are more critical in one frequency region than anothers. Similar considerations apply to the specification of maximum permissible impact transmission through floors.

The lecturer thought that these standards were not particularly high anywhere and will eventually need to be raised as people become generally more critical following the steady improvement of other factors affecting living conditions.

Although measuring methods are not identical in different countries, they are in general similar, and it should be possible to arrive at more consistent standards than are obtained at present. In fact it is possible to build a room in which the different formulae used for computation of sound insulation from measurements give the same result. If rules of measurement could be agreed upon it should be possible to establish international grading curves for dwellings of different sorts.

On Listening with Two Ears - Colin Cherry

This paper included a review of the lecturer's work on the mechanism of binaural hearing. Such theories clearly have a direct application to problems in stereophony, in addition to having importance in all subjective experiments.

Dr. Cherry stressed that in his view the ability to determine the direction of a source of sound was not the primary advantage arising from the possession of two ears, but was, in a sense, incidental to the improved faculty of being able to separate sound images. This was in any case a pre-requisite of a direction-finding ability.

The image-separation faculty was concerned as much with the past experiences of the listener as with the physical nature of the sound reaching his ears. In addition, listening to speech was associated with memory and mimicry, so that the listener tended to follow or "shadow" the words being heard with imperceptible movements of the mouth etc.

The lecturer briefly described experiments investigating the mechanism of "fusion" between sounds arriving at both ears. Where unrelated messages were received by the ears perception of the signal at one ear inhibited perception at the other. Where, however, the signals were related fusion would still take place even if one signal was artificially delayed by up to 6 ms. This delay is much greater than that associated with the distance between the ears, which is the maximum delay encountered in nature.

Experiments of this sort led to the postulation of a logical model for binaural hearing mechanisms employing an auto-correlation system in each ear channel with an analysis period of about 1 ms and a cross-correlation system, associated with the higher centres of the brain, with a period of about 6 ms.

In dealing with the "cocktail party" problem Dr. Cherry suggested that there were a number of additional factors which assisted us to separate voices in such circumstances. These included an intuitive knowledge of the prior probability of certain speech formations based on experience of speech habits and structure, even to the extent of the immediate recognition of a cliché.

Computer-Catalysed Speech Research - E.E. David, Bell Telephone Laboratories, U.S.A.

The author discussed the ways in which computers are opening up new avenues for research into the mechanism of speech, and suggested that the digital computer will play as important a part in the next decade as the sound spectrograph did in the 1950's. Such computers can save the necessity of constructing special-purpose apparatus for exploratory experiments because they can be programmed to carry out rapidly and accurately the complicated processes implied in any special theory of speech. They can, for example, analyse in detail very rapid initial information in speech sounds and they tend to encourage precise thinking because in order to programme computers the experimenter has to answer questions, in effect posed by the computer.

Problems already studied with the aid of computers concern the properties of voice excitation, refined spectrum analysis, the spectral representation of vowels and consonants, speech synthesis, speech bandwidth reduction by Vocoder techniques and the statistical study of phoneme and word usage. In such ways computers may go beyond pure acoustics, taking account of linguistic and semantic factors.

On the Perception of Sound and Speech - J.F. Schouten

The author was concerned with the manner in which a complex sound may be both analysed and integrated by the brain; for example, a sound containing a number of components at different frequencies may be heard as such or as a note of a particular timbre according to the circumstances. Because of the increasing relative importance accorded to the transients, the consonant "s" when reduced in length, will sound as "ts" or eventually "t" and the author demonstrated the effectiveness of noise in masking the audibility of the transients. He showed that small variations in pitch occur during the pronunciation of a vowel and stressed the importance of reproducing this frequency modulation if naturalness is to be maintained. This modulation is too small to be detected by a spectrum analyser employing filters of fixed frequencies and, although the author did not say so, this indicates one of the limitations of using such a system for bandwidth compression. The existence of this limitation was confirmed by other papers read later.

The lecture was noteworthy for the extremely simple, but effective, instrumentation employed in some of the demonstrations.

2.3. Contributed Papers

Section G - Speech Analysis and Synthesis

New Methods for speech analysis-synthesis and bandwidth compression - M.R. Schroeder, B.F. Logan and A.J. Prestigiacomo

A bandwidth compressor was described which divided the frequencies of individual harmonic components by 2 or 4; it also allowed programme to be slowed down or speeded up by a similar factor without change of pitch. An auto-correlation method of compression was also described which permitted a bandwidth compression of 10 and showed considerably more promise, although each method had its own limitations. This paper was a good example of the way in which experiments requiring extremely complex equipment could be much more economically simulated on a computer than by building the actual apparatus.

Speech processing by neural networks - F.L. Putzrath, T.B. Martin and J.J. Talavage

The authors had constructed an electronic model of the human auditory system from computer-type elements. Starting from the idea of coarse frequency discrimination by the cochlea and the two types of hair cells which sample the transverse and longitudinal strain in the basilar membrane, corresponding networks and electrical elements were simulated. These can further inhibit or excite neighbouring groups by means of a feedback network of the "and/or" type used in computers. Control of the threshold levels and time constants gave results showing considerable similarity to some of the properties of the ear, e.g., masking. It is worthy of note that to obtain even these limited results approximately 100 artificial neurons were needed.

Speech machine considerations - Harry F. Olson

This author was concerned with the recognition of speech, e.g. orders, by a machine. The amplitude of the speech signal was stabilised by a programme type of limiter and then differentiated to obtain the rate of change, in order to provide waveform information which was almost independent of the absolute level. The variations in spectrum with time were analysed twice. In the first case the discrimination was sufficiently coarse to neglect differences in the pronunciation of vowels by different persons; eight frequency bands and five steps of time were used. The signal in these bands was then subjected to a finer frequency analysis and the resulting signal employed to modify the output from the coarse filters.

Compensation for the speed of talking was provided by delaying the time steps until the channel received an input. The speech envelope was also examined for transients which were not detected in the coarse spectrum analysis.

This complex piece of equipment recognised orders correctly 80% of the time for 50% of the population; for the remainder the recognition fell off to almost zero.

Shape of human mouth based on speech pressure distribution close to the mouth - H.S. Leman

This paper is of interest in connection with the design of lip microphones and for this purpose the most useful part is the data on the distribution of sound pressures close to the mouth. Most data of this kind have related to distances greater than 5 cm but this author has explored the distribution in both horizontal and vertical planes for distances down to 0·5 cm. The figures given apply to a frequency band from 1000 c/s to 1600 c/s and are part of an investigation which it is hoped to publish in detail later.

The author concludes that for an artificial head a rectangular aperture, 16 × 42 mm, is a better approximation to the human mouth than a circular one 35 mm diameter but that these dimensions do not take account of the apparent variation in shape with frequency.

Investigations of the directivity patterns of speech sounds - Támás Járfás

Measurements of this type provide useful information for close-talking microphone techniques.

This paper was confined to the variation in speech quality with the angle from the head in the horizontal plane. Analysis of the distribution was carried out for both sexes for bands of frequencies containing the main formants but not over the whole spectrum. The author did, however, say that his results were in general agreement with some rather old but more extensive investigations by Dunn and Farnsworth[1] and by Flanagan.[2]

Section H - Physiological and Psychological Acoustics (Apart from Speech Analysis and Synthesis)

Some of the papers described are concerned with the measurement of the loudness or annoyance of sounds, such as programme or noise; in some cases the experimental methods employed are of particular interest. The remainder deal with stereophony and the quality of programme reproduction.

On the concept of the critical band - E. de Boer and C.E. Bos

When a tone is perceived against a background of wideband noise, only a part of the noise spectrum contributes to the masking. The ear appears to integrate only those noise components in a band of frequencies situated around that of the tone and called the critical band.

The determination of the width of this band over the audible frequency range is of importance for noise calculations. There is a large discrepancy between values obtained by various workers and this paper describes a new approach to the subject. One criticism of previous work has been the use of narrow bands of noise whose level necessarily fluctuates considerably. The authors reversed the procedure and employed a narrow gap in wideband noise of comparatively constant level. The results are in good agreement with those of Zwicker.

Loudness summation in conductive deafness - Bertram Scharf

Experiments are described on persons suffering from considerable deafness of the middle ear to see whether the summation is the same in their case as for persons with normal hearing. This proved to be the case and indicates that the summation takes place later in the auditory chain.

Methods for obtaining unbiased sound rating scales - Irwin Pollack

This paper was of particular interest because of the application of the methods described to subjective experiments in acoustics generally. The general approach was to use an iterative method whereby the results of a subjective test were used to modify the form of the test signals presented to the subject.

Audiometry and physiological noise - E.A.G. Shaw and J.E. Piercy

and

Pressure vs free field thresholds at low frequencies - Wayne Rudmose

These two papers were both concerned with the noise generated when headphones press against the outer ear. This noise, which has its origin in the pulsating blood flow in the ear, affects the minimum loudness contours and is thought to account, at least at low frequencies, for the disparity of 6 dB between headphone and free field measurements of the threshold of hearing contours.

Effects of jet aircraft noise on hearing - J.J. Knight

The paper refers to work carried out with members of the crews of Royal Navy aircraft carriers; it has, however, a much wider application to any condition when high level sounds are encountered. A retrospective survey of hearing of these men had first shown evidence of a mid-frequency hearing loss and this was confirmed by a later prospective study. The average loss is not very high but the mean is weighted by a few men with losses greater than 15 dB.

Binaural hearing and free-field effects - E.E. David and R.L. Hanson

The authors discussed the effect of delayed signals on the perceived direction of sources, which has a bearing on stereophony. For interaural time delays of > 5 ms the author confirms Cherry's statement that fusion of the images ceases. Below this value a form of position averaging may take place, moving the image in the opposite direction to that which would have been expected from a consideration of the intensity of the signals reaching the ears.

Correlation of binaural noise signals and the sound image localisation - A.V. Rimski-Korsakov

In these experiments subjects listened, with headphones, to bands of noise. One channel could be delayed or attenuated and the corresponding image positions determined. From the results the author concludes that the directional properties of hearing can better be explained by a correlation model than by any other. He confirms this by showing that two signals do not form a single image when the correlation factor is less than 0·7.

Perception of colouration in filtered gaussian noise - short-time spectral analysis by the ear - M.R. Schroeder and B.S. Atal

This is an outstandingly important paper. The authors measure the perception threshold for colouration produced in white noise by introducing into the signal chain a parallel path having a time delay. The shape of the resulting frequency response curve has a periodic character and they show that for a given curve the minimum perceptible level of irregularities is independent of the means by which they are produced and of the transient response; in addition for irregularities closer than 13 c/s no colouration is perceived. From these and other measurements they calculate a weighting function in terms of the power spectrum. They also show that a similar result can be arrived at by using an auto-correlation model having a short-time constant and conclude that later tests, not given, with non-periodic filters are more consistent with this model than with the power spectrum model.

Their results do not agree with their theory for time delays below about 5 ms and in this connection they do not appear to have explored the possibility of applying both the correlation functions thought to be necessary to account for directional hearing. The authors mentioned that in these experiments an IBM computer was invaluable.

La résponse de l'oreille aux phénomènes transitoires - L. Pimonow

This paper describes tests intended to determine the maximum frequency band necessary for faithful reproduction of programme. The subjects were presented with two sets of clicks 5 μs long from an Ionophone loudspeaker; one set was applied through a low-pass filter whose cut-off frequency was adjusted until the two sets of clicks were indistinguishable. The author states that the frequency band required was between 20 kc/s to 45 kc/s, according to the age of the listener and he concludes that such a band is required for the accurate reproduction of speech and music.

Applied psycho-acoustics - H. Burris-Meyer and R.L. Cardinell

The authors roundly denounced the commercial exploitation of music for various forms of therapeutic treatment, including music while you work, without sufficient scientific background and pointed out that some of the results might be the opposite of those desired.

Section L - Noise Control: Noise Problems in General, Insulation in Connection with Specific Noise and Vibration Problems

The accelerometer pick-up as a diagnostic tool in noise studies in buildings - F.L. Ward

The paper described techniques using an accelerometer pick-up, with associated airborne sound measurements where necessary, which have proved to be of value in field studies in the B.B.C.

Several private questions posed during the course of the Congress related to practical difficulties associated with using accelerometers and to the problem of determining sound pressure levels from a knowledge of the vibration levels which give rise to them.

Noise produced during launchings of rocket powered vehicles and human factor siting considerations - J.N. Cole, H.K. Hille, R.G. Powell and H.E. von Gierke

This paper dealt with problems of siting rocket bases sufficiently far away from towns for the noise to be bearable. It appears that persons 20 miles from the base may expect noise levels of 105 dB, mainly at very low frequencies. It is thought that the major nuisance will be damage to property rather than to hearing.

Theoretical and experimental studies of steep fronted waves in pipes - P.O.A.L. Davies and M.J. Dwyer

This work was concerned with silencers for cars and motorcycles. It has long been known that conventional acoustic low-pass filters are not effective in this respect, but the shock theory employed here gave useful design data.

Vibration and noise control by high efficiency viscoelastic structural damping materials - F. Kirschner

Such materials have been used in the B.B.C., in particular for the reduction of vibration and resonance effects in ventilation trunking. The value of the paper lies in the possibilities for extending their usefulness suggested by the wide variety of applications carried out and described by the author.

A proposed sound-absorbing device in the high velocity duct systems - Masayuki Matsui

This paper is of particular interest in view of the growing use of these systems in the ventilation of buildings.

Prof. Masayuki gave details of devices in which he endeavoured to separate the d.c. and a.c. components in the air stream. Perforations in the duct wall were covered by glass cloth and an air space was provided between the cloth and the absorbent material. Attenuation of sound transmitted along this duct for different types of construction, both with and without airflow, were given.

Effect of reverberation on reaction to impact noise - G.J. Thiessen and K. Subbaroo

The paper dealt with one of the factors which affect the "nuisance value" of noise, and referred first to the effect of reverberation by which the tolerance to impact noise is lowered due to a reduced ability to establish the direction of a noise. The authors then described experiments using electronically-produced pulses, which demonstrate a psycho-acoustical effect of reverberation in addition to the directional effect whereby the tolerance level is lowered by an amount which may be as much as 4 dB.

This effect could well be of significance in establishing noise criteria for use under different conditions in broadcasting studios.

Experimental buildings for sound insulation studies - O. Brandt and S. Wahlström

This was the companion paper to that by Brandt and Westerberg referred to on page 14, and dealt with the familiar problem of accurately estimating the performance of partitions from laboratory sound insulation measurements. The degree of insulation achieved in practice is often less than that anticipated, mainly due to flanking transmission and the change in edge conditions of the partition.

For this reason a number of experimental buildings had been built as models for bigger buildings (such as a large studio centre). They consist of several units of the planned building but with facilities for changing the walls, ceilings, etc. An interesting feature of the paper was the description of an internal cladding partition for use in flanking transmission experiments.

This partition could be fitted as a lining to a wall and it is conceivable that a modified form might be of use in the B.B.C. as a permanent addition to a wall where a sound insulation problem has arisen in an existing building.

Section M - Room Acoustics. Sound Absorption and Insulation in General Acoustic Properties of Rooms.

In this Section a group of papers was concerned with the design of auditoria specifically, although many of the ideas involved are naturally of interest in connection with any large music room or studio.

The problems of sound insulation were studied from a number of points of view, the papers on the whole being noteworthy for the realistic approach to sound insulation and its measurement under conditions found in practice.

The measurement of diffusion in rooms, and the design of laboratory facilities formed the main subject matter of several papers.

Pulse tests in acoustic models - J.P. Lochner and J.F. Burger (South Africa)

This paper dealt with experiments made in a 1 : 16 scale model of an auditorium in Pretoria University and of a reverberation room. Magnetic recordings replayed at one-sixteenth of the recording speed were used to reproduce a normal time-scale. Values of word intelligibility derived from articulation tests carried out in the full-scale rooms were compared with values computed from pulse tests in the models, with good agreement.

Although this work was restricted to questions of speech recognition in a room, it has interest as an example of a successful model experiment. With development, such techniques, already used in Research Department for certain special investigations, could save time and expense in full-scale studios for some of the simpler problems.

The dependence of reverberation time upon seat spacing - L.P. Delsasso (University of California)

Experiments on the efficiency of absorbers arranged with different configurations are in general of great interest, but are often difficult to carry out for economic reasons. This paper described the result of a few experiments on changing seat-spacing in three enclosures, a reverberation room, an all-purpose auditorium of 600,000 cu ft seating 2560, and a new "teaching theatre" of 120,000 cu ft seating 600. Doubts about the value of this work were voiced privately and Beranek raised a query during the discussion as one of the results was at variance with measurements that he had reported.

Sound insulation requirements in building practice - G.O. Jorgan (Norwegian Building Research Institute)

This paper describes a system which is an attempt to translate the results from international acoustics research to practical applications in building practice. The standard curves for different requirements having been specified, methods have been developed by which it is possible to estimate, with a fair degree of accuracy, the sound insulation to be expected in a given building situation. Simple calculations are made which involve a knowledge of the measured airborne sound insulation of a partition, the area of the partition, the volume of the receiving room, the reverberation time of the receiving room and an approximate correction for the estimated category of flanking transmission ("normal", "great", "very great", etc.). The calculated "airborne sound number" of the partition is then used to characterise the construction.

Although the system appears, on the face of it, to be somewhat crude, the fact that it is also reputed to be effective in practice is of great interest, and leads to the possibility that a certain amount of "intelligent guesswork" about flanking transmission in some cases might be more accurate than had been supposed.

Acoustics of music rooms - V.O. Knudsen (University of California)

There was an extremely good attendance for this paper which the author described as the "second edition" of his paper of 1931. It revised the principles of designing rooms for music. He did not agree either from studies made on two-dimensional models, or experience, that there was any real advantage to be gained from the use of rectangular plans over shapes with moderately diverging side walls. He thought that it was desirable to aim for first reflections within the first 30 to 40 ms followed then by a succession of reflections giving a "relatively smooth but slightly undulating (simulating a vibrato) reverberation". From the point of view of the shape of the reverberation curve, he believes that the criterion that makes the change of *loudness level* the same for all frequency components during the decay should be used; this leads to a rising reverberation time at low frequencies.

A reverberation chamber for power level measurements of sound sources - W.W. Lang

This paper was concerned with reducing the number of measurements necessary to obtain the total acoustic power radiated by a source, in this case a machine. Instead of free field conditions a large (230 m^3) rectangular reverberation room was employed. The room surfaces were specially treated and reverberation times in excess of 40 sec were obtained at very low frequencies. Diffusion in the bare room was found to be good and the results agreed more closely with semi free-field measurements, i.e., source resting on one totally reflecting plane, than when diffusers were used.

Measurements of flanking transmission in a test house in full scale - O. Brandt and G. Westerberg (Royal Institute of Technology, Stockholm)

The paper described briefly the types of measuring technique for investigating different routes of flanking transmission in the laboratory. One of the experimental methods of identifying and measuring flanking transmission involved fitting an additional partition as internal cladding to one or more of the walls of an experimental room during the course of an investigation, in order to increase the sound insulation of a particular wall.

Some of the results quoted referred to the effects of breaks in concrete structures and the additional effect of plastering over the edges of the break. This work is of special interest in view of the extensive use of such gaps as an isolation measure in B.B.C. studio premises.

Transient sound transmission losses - A.C. Raes (Brussels)

The paper discussed methods of measuring sound insulation using small samples, sometimes in the factory, with short pulses. The author claimed considerable success with the method, an interesting feature of which was the use of an exponentially shaped pulse. He did, moreover, claim that this method was generally more accurate for practical purposes than the ISO standard procedure. When there was a small difference between his measurements and the ISO he attributed this to a failure in the ISO method of measurement.

Prinzip und Anwendung einer neuartigen Wandverkleidung für reflexionsarme Räume - P. Rother and J. Nutsch

The authors describe the treatment of a large dead room, approximately 1150 m^3 free space, the primary consideration being low cost of materials. They have used a "wedge" type treatment 1 m thick, of unconventional form, built up from 5 cm thick slabs of rockwool of three different densities and about 10 different sizes; each "wedge" consisted of about 50 different pieces stuck together. Although the material may have been cheap the cost of labour must have been enormous.

The new acoustic facilities at U.C.L.A. - R.W. Lennard, I. Rodnick and L.P. Delsasso (California)

The paper described the plans for the new laboratories at present being built. They include a reverberation room of 13,700 cu ft, a dead room with a floor area of 734 sq ft, and a transmission room which is used in conjunction with the reverberation room for measurements of sound transmission through partitions. Two features of special note are the proposed use of air springs (i.e. pneumatic pistons supplied from a central compressed air supply) to isolate the inner shells of the special-purpose rooms, and the design of a door between transmission room and reverberation room which it is hoped will provide about 100 dB sound insulation. This expectation is based on the use of two doors giving 40 dB insulation separated by a large quantity of fibreglass providing about 20 dB insulation. Doubts were voiced regarding the likelihood of this result being achieved in practice in such a simple way, especially as a correspondingly efficient door seal will be required.

The influence of acoustics on design and construction of buildings in America today - R. Neuman (U.S.A.)

This contribution, which was presented in a most amusing and witty style, did not offer any novel technical ideas. An interesting point, however, is that the lecturer had begun to find signs that a few young architects had sufficient basic knowledge of acoustics to avoid fundamental, and irreparable, design faults in buildings.

Acoustic effects of movable sound reflectors in the auditorium - Y. Funakoshi (Tokyo)

This paper was of interest mainly because it referred to one method of obtaining a degree of variable acoustics.

The necessity for movable reflectors arose from the recent provision of a number of community centres throughout Japan. The auditoria in the centres had to be designed to be suitable for a variety of purposes. Curves of reverberation time showed the degree of variation in reverberation time actually achieved in a number of such centres in Japan.

Measuring methods for distinctness in time and frequency in studio acoustics - J.J. Geluk (Netherlands Broadcasting Union)

The methods described were developed as a result of the increasing interest in stereophonic broadcasting. The author applies the term "distinctness in time" to a stereophonic system as the counterpart of "definition" in the studio itself, and "apparent diffusivity" as the counterpart of "directional diffusivity" (as defined by Meyer and Thiele).* Experimental methods involve the use of frequency-modulated tones. Comparison is then made between the frequency of the initial sound and that arriving at a later instant. The techniques are restricted in application to microphone systems and do not have any direct subjective meaning for a listener in the room. The philosophy behind this type of examination is that one should test a room in the same way that one might test a piece of electro-acoustic apparatus, such as a tape recorder. The implication is that with stereophonic systems it is better to make measurements of the more subtle acoustic quantities through the system than in the room itself.

A method for the investigation of sound diffusiveness in rooms - G.A. Goldberg (U.S.S.R.)

This author also referred to the work of Meyer and Thiele on the measurement of diffusion. He then described an experimental method using short pulses for providing the polar diagrams of reflected sound arriving at a point in an enclosure during reverberation. The device is essentially the same as the one seen by the authors of this report during a tour of the Danish acoustical laboratory, with the exception of the addition of a method for identifying the direction of a reflection without ambiguity. The source of sound for the experiments was a spark.

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* The work of Meyer and Thiele on diffusion was referred to several times during the Congress. They examined the response of a room to pulses in a number of directions, with a highly-directional microphone, and computed a quantity called the "directional diffusiveness" or "directional diffusivity". (Reference 3)

The use of lead in improving sound transmission loss - P. Ostergaard (New Jersey)

The author described basic methods of using lead sheets and showed experimental results of measurements. He claimed that compared with other basic materials the use of lead provides the maximum sound insulation per pound weight, at moderate cost.

Section N - Electroacoustics: Transducers, Measuring Methods in General

Details are given here of the papers relating to stereophony and to distortion, microphone, loudspeaker and headphone measurements.

Magnetic recording of audio signals at low tape speeds - K. Teer, E. de Niet and D.L.A. Tjaden

This paper gives details of a system of improving the performance of recording machines for tape speeds of $1\frac{7}{8}$ in/sec (4·75 cm/sec). The frequency range is split and a head with a comparatively large gap is employed to record frequencies up to 2 kc/s; above this frequency a second, smaller, gap is used spaced 0·04 in (1 mm) along the head. The signal recorded by the first gap is reduced by the bias in the second gap but the loss is small; on the other hand different bias currents are applied to the two gaps, each being optimum for the frequency range concerned. The replay head has a single gap and it is claimed that the time delay, 20 ms, involved in the tape passing through the two recording gaps, is imperceptible.

From the data it is difficult to estimate the actual improvement obtained by this system over a conventional one.

Audio frequency non-linear distortion. Measurement by wide band noise - B.E. Bang

and

Some results on using a signal with a continuous spectrum for distortion measurements - S. Boel Pedersen

These papers describe measurements employing a noise signal covering a wide frequency-range but from which a narrow band of frequencies has been removed. The power which occupies this band after the signal has passed through the apparatus under test is used as a measure of the non-linearity of the system. In subsequent conversation the authors agreed that in practice it is difficult to determine the type of the distortion terms from the results. If the distortion varies with frequency no indication is given of the band concerned, and it is not surprising therefore that measurements made on a hearing aid having the usual irregular frequency response bore very little relation to those made by employing pure tones. The authors have not yet attempted to correlate the subjective effects of distortion in a system with the objective results given by their apparatus.

Power handling capacity of loudspeakers - C. Bordone-Sacerdote

Sẽnora Sacerdote gives the results of experiments recommended by IEC 29 for testing the power handling capacity of loudspeakers over a period of time. Changes are produced in the fundamental resonance frequency and on frequency response during the life test; these changes are given and it is shown that some are permanent.

On the other hand, the results are in no case related to normal life tests employing programme, and the question as to whether the recommendation gives realistic data is left unanswered. Subsequent conversations with other delegates suggest that it does not do so.

On the use of warble-tone and random noise for acoustic measurement purposes - J.T. Broch (Brüel and Kjaer, Denmark)

The requirements for acoustic test signals were briefly discussed and the conclusion drawn that either warble-tone or narrow band white noise are the most convenient signals. In most cases, there is little significant difference between the two signals but an important exception arises where non-linear effects can be expected, when random noise is preferable. Examples of non-linear absorption occur with resonators with narrow necks and although a figure as low as 65 dB has been suggested as a possible level where non-linear effects may become important a level of around 100-110 dB is probably more realistic. Measurements of the attenuation characteristics of a particular non-linear resonant system, namely a car silencer, were described.

Binaural audition and the design of a push-pull stereophonic loudspeaker - F.H. Brittain

This author indicated his ideas of the requirements for good stereophony and gave constructional details of a wide range loudspeaker, employing 5 units which was claimed to give very little distortion. In this design, the units are mounted in a vertical row; further details are given in Research Department Report L-053. The loudspeaker is rather directional in the vertical plane but neither this nor any of the other design features are specially applicable to stereophony. Some of the statements made were highly questionable, for example, that little directional information is obtained below 300 c/s in a listening room.

A new determination of the acoustical impedance of human ears - M.E. Delany

This account of work carried out at the N.P.L. gives detailed results necessary to improve the design of artificial ears used in audiometry and headphone development. Measurements were made of the pressures developed in the ear from a high impedance sound source; the effects of leakage caused by an imperfect seal between a headphone and the ear are explored and the variation between different subjects is given. The new median values are no doubt more accurate than those of previous determinations but, although the author did not say so, the spread shown between the results for different subjects indicates that the best aid to higher accuracy in audiometry would be the development of transducers of lower acoustic impedance.

Contrôle des Lecteurs Stéréophoniques par Disques de Fréquence Glissante - D.J. Dion

The paper describes means for testing stereophonic pickups both for frequency response and crosstalk. A special disk has been prepared with a gliding tone for measuring directly the response of the A and B outputs and obtaining the corresponding sum (A + B) and difference (A - B) signals. Details are given of a device which permits 1/3 octave filters to be used synchronously with the record when crosstalk is being measured, e.g. from the A to the B channel.

The effect on stereophonic reproduction of frequency-dependent crosstalk between left and right channels - H.D. Harwood

The paper describes work carried out by the B.B.C. in connection with permissible limits of frequency-dependent crosstalk between left and right hand channels of a stereophonic system. Measurements were made of the image spread produced, and the investigations included the effects of such variables as listening level, observer's position, acoustics of the listening room and the restriction of the high or low frequency spectrum of the programme.

Miniature pressure microphones - G. Rasmussen

The author is responsible at the firm of Brüel and Kjaer for the design of condenser microphone standards and gives details of the construction of a family of pressure operated instruments ranging from 1 in diameter to 1/8 in diameter. At high frequencies microphones of this type become directional and it is to overcome this effect that the porous Romanov disk is employed on the "apple and biscuit" microphone. For some reason, which subsequent conversation failed to elicit, this designer prefers to use a non-porous obstacle to make the microphone response approach the omnidirectional condition. The results he showed are not so good in this respect as those obtained in the B.B.C. from the Philips microphone type 3921/00 with a porous disk. On the other hand the response and sensitivity he obtained from his smaller size instruments should make them invaluable for physical measurements.

High-quality push-pull condenser transmitters - G.M. Sessler and J.E. West

These "transmitters" are headphones constructed of two thin metallised mylar diaphragms which have been permanently polarised to form electrets, the electrical equivalent of permanent magnets. The system is operated in push-pull but in practice it is necessary to connect balancing capacitors across the diaphragm terminals if low distortion is to be achieved. The frequency response claimed is extremely uniform and the power handling capacity adequate, but the acoustical impedance is somewhat high.

Section O - Physical Acoustics. General Theoretical Acoustics, Radiation Problems, Non-Linear Acoustics, Etc.

A new method for determining the end correction of pipes by means of pulses - M. Louden

Several theories have recently been formulated concerning the end correction which must be applied to the physical length of a pipe in order to be able to calculate accurately the resonance frequencies. Some of the theories do not agree and this paper gives details of experiments performed with pulses transmitted along the pipe to determine which theory is correct. The pulse and its echo are analysed into their Fourier components and from this analysis the end correction and its dependence on frequency is obtained. The results are in good agreement with those predicted by Lerine and Schwinger[4] and by Weinstein.[5]

Section P – Mechanical Vibrations

Some of the aspects of vibration have direct reference to noise problems, and one of the papers in this Section was of special interest.

The effect of cuts in damping tapes - E.G. Parfitt (Imperial College, London)

The damping tape referred to consists of a metal tape or foil coated with an adhesive compound by which it is attached to a metal panel, to provide damping of vibration of the latter, as a result of the high internal frictional properties of the compound. Developed originally for use in aircraft these tapes are finding increasing use wherever metallic panel resonances lead to undesirable acoustic effects. It has been shown, theoretically, that the damping introduced by such tapes is substantial only in a limited frequency range determined by the relative dimensions and elastic constants of the panel, the adhesive compound and the metal foil. In practice, however, the frequency range is not as limited as theory indicates and it has been shown experimentally that wrinkles and cuts in the tape are responsible for this phenomenon. The paper discussed a theory explaining the experimentally observed facts and leading to a determination of the optimum spacing of cuts in a tape. This spacing is convenient in that it relates only to the properties of the tape itself, and not to the application. Tapes of this kind have been employed experimentally for panel damping problems in the B.B.C. and will undoubtedly be used more generally in the future.

3. SPECIAL VISITS

3.1. The Acoustical Laboratory, Akademiet for de Tekniske Videnskaber (Academy of Technical Science)

This laboratory is the central laboratory for acoustics in Denmark, and includes in its work, teaching, research and official testing in room acoustics and electroacoustics.

Plans have been completed for new laboratories which will include two new dead rooms, one with a working space of about 1000 m^3 and the other 60 m^3. The cost of these is expected to amount to about a quarter of the total (£400,000) and a considerable amount of work is being devoted to finding the best form of treatment. The room is intended to be used for the same types of measurement as the new room at the B.B.C. Research Department and a similar depth of treatment, 1·45 m, is envisaged. Tests have been made of the reflection coefficients at normal incidence for wedges of various materials and shapes; the best results have been obtained with German "Sillan" of density 100 kg/m^3, using a taper angle of 15° and a 30 cm square base; with this construction the reflection coefficient is below 10% down to about 50 c/s. The cost of this treatment per unit area will be about three times that proposed for the B.B.C. Research Department room.

The laboratory has been informed by the N.P.L. of the standing waves experienced in their rooms at high frequencies, and the B.B.C. measurements of their absorbent wedges. Tests are therefore being made to see if the Danish wedges are likely to give trouble in the same way. Short pulses of tone are applied to a small omnidirectional electrostatic loudspeaker and the sound pressure reflected from the wedges is measured at various angles to the normal. Unfortunately, owing to the small size and poor acoustic properties of the dead room available for making the tests, all dimensions and distances had to be scaled down to one sixth of the original size and it has not been practicable to measure the reflected sound at angles of 70° to 90°, the real region of interest. Tests with solid reflecting wedges have failed to reveal any benefit from the usual crisscross pattern of wedge tips. A considerable amount of informal discussion took place during the conference and an improved method was suggested of making comparative reflection measurements in a travelling wave tube for different angles of incidence.

Work is also being carried out on the calibration of microphone standards by reciprocity. It is hoped that a modification of the usual method of coupling capsules to one another by means of an acoustic impedance will give a simple but very accurate measurement.

The most interesting demonstration from an acoustic point of view was that of the "acoustic goniometer". The instrument is similar in principle to that referred to by Goldberg in the contributed papers. The principle is that of the radio direction-finder but using two figure-of-eight microphones in place of the loop aerials. When used to investigate the reflection response of a large room the operation of the instrument is improved by the use of an electronic gate which completes the circuit for a few milliseconds during the decay of sound. This gate can be adjusted to operate at a suitable instant with the aid of a conventional oscilloscope display, showing echo amplitude.

An example of the directly practical testing work of the laboratory was given in an arrangement for testing noise from water taps.

A mobile laboratory, used for such an investigation as aircraft noise on airfields, was on show. It contained standard Brüel and Kjaer equipment but was, nevertheless, quite small, being arranged in a Volkswagen van, which could be driven into factory shops when required.

3.2. Concert Halls

Both of the concert halls visited, at the Tivoli Gardens and at the Broadcasting Studios, have already been referred to in Research Department Reports A-031 and A-049, the Tivoli Hall being described in some detail in the latter.

The Tivoli Concert Hall

This hall was opened in 1956 and has a volume of 12700 m^3, seating nearly 1800 people; it is reputed to have a reverberation time of 1·8 to 2·1 sec when empty and 1·1 to 1·5 sec when full. It has a narrow fan-shaped plan and the stage area possesses a ceiling in the form of a reflector directing sound towards the audience.

The Tivoli Orchestra could fairly be described as a light orchestra although it played music by Beethoven and Carl Nielsen. Despite the small size of this orchestra, it was still possible to get an assessment of the somewhat indifferent qualities of the hall. For the higher frequencies, there was an impression of detached reverberation associated with the ceiling and, to a lesser extent, the side surfaces of the hall. Sitting in the centre of the hall, the direct sound of the strings and brass was quite good, but the woodwinds were very attenuated, probably because of the flat seating arrangement of the orchestra. In the more openly-scored passages, the woodwinds appeared to originate at a point above the orchestra; presumably because of the presence of the stage reflector. The response of the hall was in general excessive in the bass and in some passages this was sufficiently pronounced to be irritating.

The Radio Concert Hall

A special concert including works by Handel, Mozart and Carl Nielsen was given by the Symphony Orchestra of Radio Danmark under Mogens **Wøldike**, with N.H. Nielsen as the organist. A source of considerable disappointment to a number of delegates to the Congress was that although the hall is equipped with what appears to be a superb organ, the only organ work played was a Handel organ concerto which required only a minute section of the instrument.

This hall is an extreme example of the use of a fan-shaped plan, the ratio of breadth and height to the length of the hall being particularly high. It has a poor reputation for its acoustics although attempts to improve it by providing Perspex reflectors hung from the ceiling at different levels have been made. It is unlikely that these have had any great effect, except perhaps at high frequencies, and they may well have made matters worse for listeners sitting in the upper balcony where listening conditions are unsatisfactory. At a point slightly off centre in the lower gallery, chosen because it was thought likely to be a good position in this hall, conditions were very much better. Even here, however, the impression of the orchestra was somewhat unfamiliar to one used to halls with a traditional ratio of dimensions.

4. CONCLUSIONS

Many of the papers presented at the Conference have provided useful information and ideas connected with the work of the Corporation. Equally important has been the opportunity for discussion and consultation with other delegates working in the same or allied fields. These opportunities would have been even more numerous if the contributed papers had been circulated well in advance and it is to be hoped that this will be possible on the next occasion. It would also be helpful if the length of each paper could be somewhat increased as it is difficult to compress a worthwhile contribution into the space allowed at present. To make this possible it would be necessary to cut down the total number of papers.

This Congress made very evident the increasing area of application of acoustic principles, coupled with a greater degree of specialisation and complexity in each section. Unless some major change in the organisation takes place it is likely that soon it will not be possible to cover the whole field of acoustics in the one Congress.

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